Assessment cover

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Module No:	**ENGR7004**	Module title:	**Composite Design and Impact Modelling**

Assessment title:	**Assignment 2**

Due date and time**:**	**Friday Week 12 at 13.00 hrs**

Estimated total time to be spent on assignment:	50 hours per student

LEARNING OUTCOMES

On successful completion of this assignment, students will be able to achieve the following module learning outcomes (LOs):
LO 1 In relation to the crashworthiness of vehicles; demonstrate a deep and systematic understanding of material behaviour, explicit FEM and vehicle manufacture, design and testing. Identify relevant industry safety standards and demonstrate compliance for vehicle impact.
LO 3 Critically evaluate the effectiveness of the design concepts whilst dealing appropriately with incomplete and contradictory data.

Engineering Council AHEP4 LOs assessed		
LO number	**LO text**	**Met? (Y/N)**
M2	Formulate and analyse complex problems to reach substantiated conclusions. This will involve evaluating available data using first principles of mathematics, statistics, natural science and engineering principles, and using engineering judgment to work with information that may be uncertain or incomplete, discussing the limitations of the techniques employed.	
M3	Select and apply appropriate computational and analytical techniques to model complex problems, discussing the limitations of the techniques employed	
M4	Select and critically evaluate technical literature and other sources of information to solve complex problems.	
M5	Design solutions for complex problems that evidence some originality and meet a combination of societal, user, business and customer needs as appropriate. This will involve consideration of applicable health & safety, diversity, inclusion, cultural, societal, environmental and commercial matters, codes of practice and industry standards.	
M17	Communicate effectively on complex engineering matters with technical and non-technical audiences, evaluating the effectiveness of the methods used.	

☑ I declare that the work submitted is my own and that the work I submit is fully in accordance with the University regulations regarding assessments *(www.brookes.ac.uk/uniregulations/current)*

SELF EVALUATION

Enter a grade (written in alphanumeric form (A+ etc), based on the given marking matrix) and write comments on why you think that grade is correct in terms of the marking criteria given in the marking rubric.

Section	Grade	Comments
Introduction	A*	I feel the grade is reasonable as I have met at least 85% of the requirement to fulfil each of (AHEP4 M4,M5)
Procedure	A	I feel the grade is reasonable as I have met at least 75% of the requirement to fulfil each of (AHEP4 M3)
Results	B*	I feel the grade is reasonable as I have met at least 65% of the requirement to fulfil (AHEP4 M2) criteria being in a position to identify and analyse the given problem statement and effectively addressing the limitations with minor areas of improvement necessary to demonstrate my understanding.
Discussion	B*	I feel the grade is reasonable as I have met at least 65% of the requirement to fulfil each of (AHEP4 M2,M3,M5) by able to be in the position to apply computational and analytical techniques to model problems and effectively able to identify and list down the limitations associated.
Effort and Innovation	A	I feel the grade is reasonable as I have met at least 75% of the requirement to fulfil each of (AHEP4 M4,M5) as I have tried to identify the limitations associated with model and tried to correlate the influence of external load factor using Half model as well as the individual cell module.
Presentation	A*	I feel the grade is reasonable as I have met at least 85% of the requirement to fulfil (AHEP4 M17) and have written the report in simple language covering all the critical points which can be understood by even the non-technical audiences reading the report.

Introduction

In recent years, the automotive industry have been predominantly focusing on lightweighting, referring to the process of designing and manufacturing of components using materials which are light in weight without compromising the performance and strength, considering the sustainability aspect. One such example of research in this area has been for the design of lightweight automotive battery pack enclosure. Among the possible options available, use of composites materials have been identified as the most ideal choice, considering the wide range of advantages they offer. It is important to study different parameters associated with the designing of the battery pack enclosure for high strength and crash resistance considering the safety parameters. FE element tool has therefore been considered as an effective approach for estimating and validating the crash worthiness of the design model. In this approach a mathematical model is used as an approximate representation of the design model. The accuracy in results of the representative design depends on the robustness, precision and consideration of all the influencing parameters and factors of the developed model in real-world (Pan, et al., 2020). This can be improved by model verification and validation.

The following report focus on the "Crash analysis of a battery enclosure", wherein a physical crash test on the battery enclosure was performed and simulated in LS-DYNA to estimate the durability and performance of the designed battery enclosure using composite materials.

As a part of the following case study, a battery enclosure model intended for mass manufacturing have been considered. For the selection of the composite material the following factors were considered.

- Availability
- Design Flexibility
- Cost per Unit
- Performance properties
    - Strength
    - Temperature resistance
    - Electrical resistance
    - Strength to weight ratio
    - Corrosion resistance
    - Dust proof
    - Water repellent
- Manufacturing efficiency
- Sustainability

Considering the above listed factors the following set of materials were selected for designing the battery enclosure after performing analytical calculations.

Envelop	Side Impact Structure	Front Impact Structure
E-Glass & Kevlar pre-impregnated with Flame retardant epoxy	S-2 Glass with Epoxy	S-2 Glass with Epoxy

Approach

The finite element method allows us to predict and estimate the stress, strain, behavioural effect etc for a specified crash scenario. For simulation and analysis of any design model, various approaches can be carried out considering the limitations and advantages associated with them. For the following analysis Half-Body structure of the model was considered to overcome/avoid limitations associated with full-body model such as the requirement of extra computational power and longer simulation time, while the drawback associated with the approach is the trade-off in accuracy of the result. In order to reduce the variations of the result in comparison to the full body model, compensation for influence of the remaining half using suitable boundary condition and other alternative such as use of springs to represent the stiffness of the remaining part of the body were considered. A surface CAD model of the design and its meshing was done using external CAD/CAE software before performing analysis and simulation using OASYS software package.

Procedure

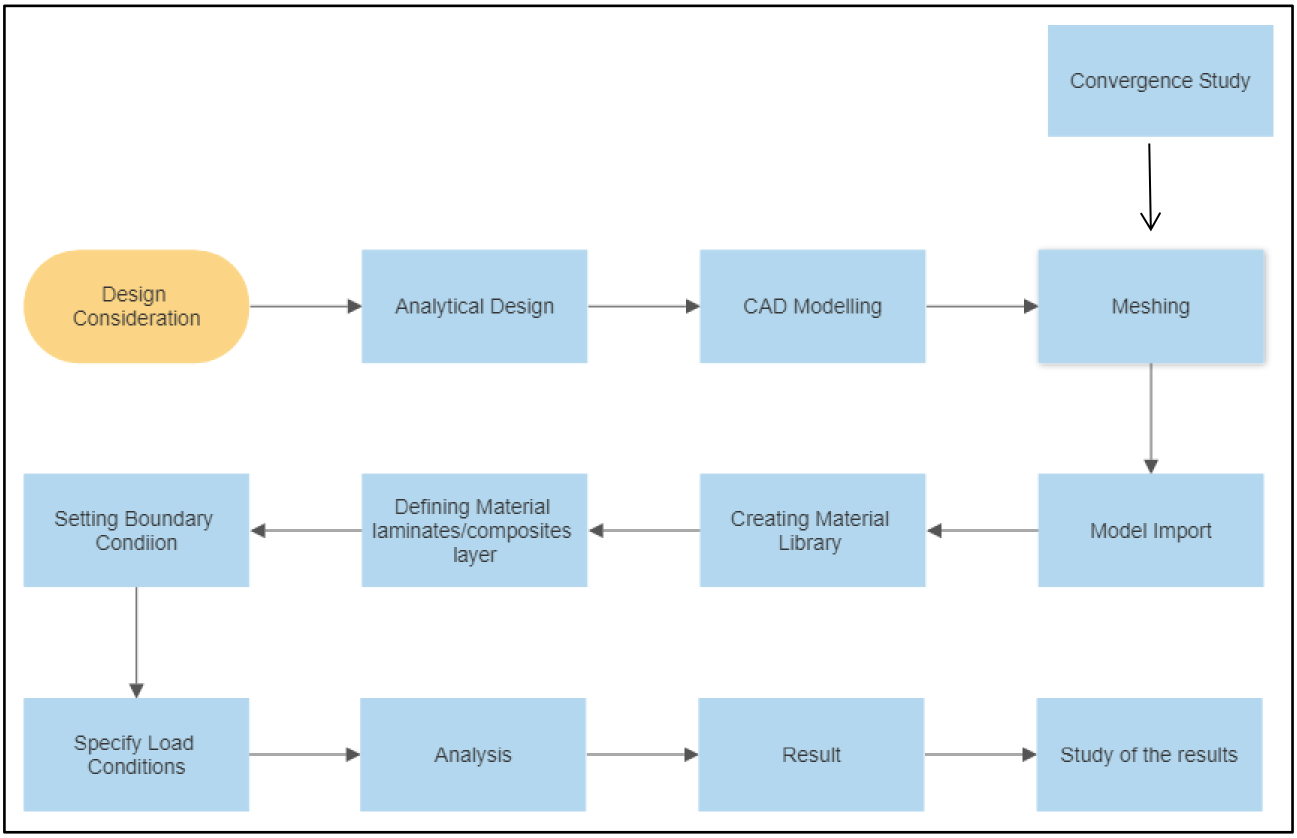

Figure 1 Systematic approach for performing crash analysis and solving the problems

Using the FE method the analytical design of the model can be validated and also it can be used to verify if the model meets the design requirement of protecting the battery module from external factors. In case of failure, the influencing parameter can be identified so that an alternative solution can be identified to meet the requirement, this makes the development process more efficient.

	Actual Designed model dimensions (m)	Simplified Model dimensions for simulation (m)
Total Length	2.125	2.1
Total Width	1.435	7.05E-1
Total Height	1.70E-1	1.70E-1
Envelop Thickness	4.625E-2	4.625E-2
Side Impact Thickness	4E-3	4E-3
Front Impact Thickness	12E-3	12E-3

Table 1 Dimensions of the model

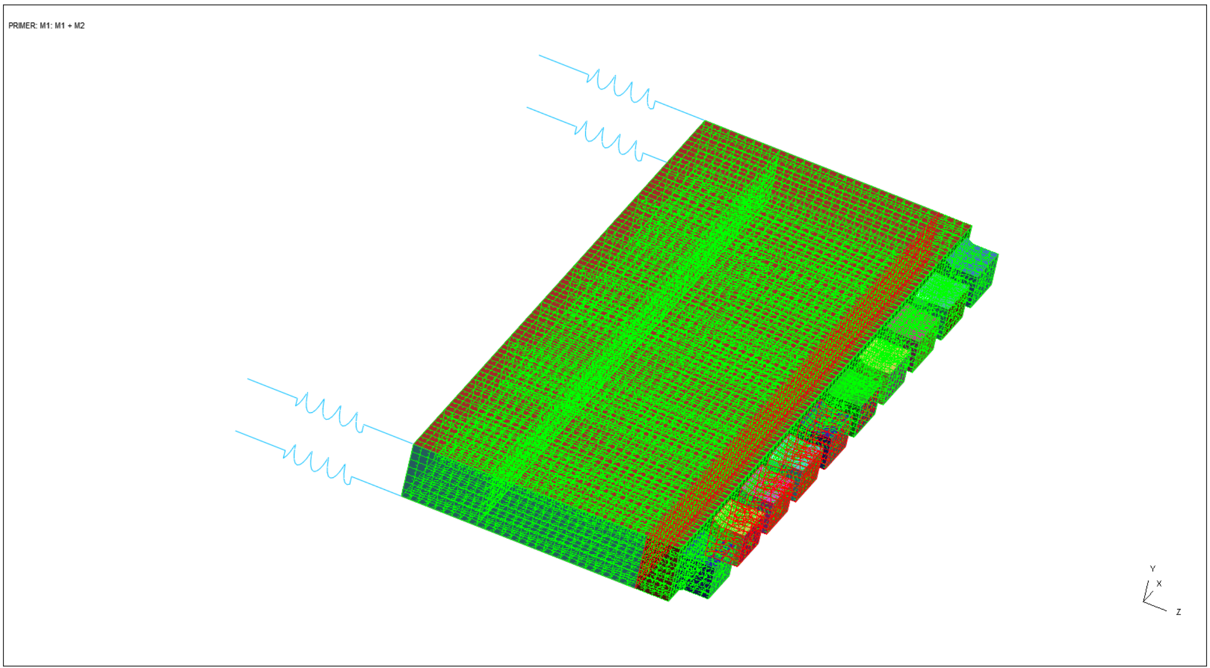

Figure 2 Model for side impact crash analysis with boundary conditions defined

Elements type

In FEA, several factors affect the accuracy of the results, one of them is the element type used and the size of the elements. The meshing has significant role in The simulation time majorly depends on these two factors. Since the designed model is simple in structure, quads type mesh elements were used. The major advantage of using a quads type meshing is the their ability to capture sharp features, requirement of lower computational resources and simplicity (Bommes, et al., 2013).

Convergence study refers to stability and convergence of the numerical solution and enables to identify the optimal mesh size to predict accurate results, however convergence study for the designed model could not be carried out due to larger simulation run time for small mesh element size. Although the lowest possible mesh size (25mm) was considered for the simulation with an expectation of achieving the close to accurate results.

Material Model 58: Laminated Composite Fabric model enables to

The MAT58 a continuum damage model was used for defining the composite laminate material. This model uses a fixed residual stress value to demonstrate load carrying capability even after initial failure until it does not completely wear down (Shi & Xiao, 2018). This makes the use of this model more effective for crash analysis.

Density	EA	EB	EC	PRBA	GAB	SLIMS	T Size	GMS
1900	2.4E10	2.3E10	0	0.07475	3.6E9	1	1E-8	0.-217
XC	**XT**	**YC**	**YT**	**SC**	**E11C**	**E11T**	**E22C**	**E22T**
5.18E+08	4.78E+08	4.55E+08	3.87E+08	7.80E+07	0.02158	0.0199	0.01978	0.0168

Table 2 MAT_058 parameters for E-Glass

Density	EA	EB	EC	PRBA	GAB	SLIMS	T Size	GMS
1400	7.50E+10	6.00E+09	0	0.0272	2.00E+09	1	1E-8	0.0575
XC	**XT**	**YC**	**YT**	**SC**	**E11C**	**E11T**	**E22C**	**E22T**
4.60E+08	5.20E+08	4.60E+08	5.20E+08	1.15E+08	0.00613	0.0069	0.077	0.0867

Table 3 MAT_058 parameters for Kevlar

Density	EA	EB	EC	PRBA	GAB	SLIMS	T Size	GMS
2000	5.90E+10	2.00E+10	0	0.095	9.00E+09	1	1E-8	0.01833
XC	**XT**	**YC**	**YT**	**SC**	**E11C**	**E11T**	**E22C**	**E22T**
1.24E+09	2.00E+09	2.00E+08	8.20E+07	1.65E+08	0.021	0.334	0.01	0.0041

Table 4 MAT_058 parameters for S-Glass

Contact Conditions

Specifying contacts between two bodies is crucial in prediction for FE simulations. Automatic General surface contact is used to establish the contact between all free edges of the shells between attenuator and the battery enclosure.

Boundary Conditions

Front Impact	Side Impact
Last Surface of the wall is fixed in (X,Y,Z) direction using the SPC option in Bound.	Springs were used to represent the stiffness of the object in rear direction
A symmetry plane is applied to the mid plane to mimic the other half of the model	The end nodes of the springs were fixed in (X,Y,Z) direction using the SPC option in Bound.
The nodes are given a constraints to show displacement only in x-direction (i.e. in the direction across the impact).	The nodes are given a constraints to show displacement only in z-direction (i.e. in the direction across the impact).

Table 5 Boundary Condition specified for either test conidtion

The average total Spring Stiffness was calculated using the equation $K = \frac{EA}{L}$ and the total stiffness was distributed among no of Springs used to replace the represent the remaining half of the body.

	Thickness	Length	Area	Spring Stiffness
Side A	4.65E-03	2.1	9.77E-03	6.46E+08
Side B	8.65E-03	1.70E-01	1.47E-03	9.73E+07
Side C	4.65E-03	2.1	9.77E-03	6.46E+08
Side D	8.65E-03	1.70E-01	1.47E-03	9.73E+07
			Average Total Stiffness	1.49E+09
Effective Value of E	4.67E+10		No. of Springs	4
Remaining Length (m)	7.05E-01		Individual Stiffness (N/m^2)	371775523.4

Figure 3 Calculation of Spring Stiffness

Load Conditions

Since we have modelled half battery enclosure the load conditions used for analysis for the Rigid Wall are specified below.

- Mass= 650Kg
- Velocity=13.86 m/s

Results

	Max Displacement Front Impact (m)	Max Displacement Side Impact (m)
Without Attenuator	51.48E-3	45E-3
With Attenuator	21.41E-3	9E-3

The first step after completing the FE simulation is to validate the model by comparing the obtained results with the results calculated using the analytical approach. Once the model is validated and verified only then the results from the simulation should be considered else it can be said that there is an error associated with either of the approach.

In the following case considering the initial results obtained from the analysis showed high deflection of the battery model indicated under-design of the model for the specified load condition. In order to minimise the deflection of the battery enclosure to protect the battery, an impact attenuator needed to be designed so that the impact energy could be absorbed reducing the impact forces reaching the battery enclosure.

For the case study Aluminium 6061t6 was considered as the material for modelling the impact attenuator. In both the case the it was evident that the impact attenuators were able to reduce the influence of the external load, but only for the side impact test the result were within the considerable limit. For front impact the deflection were still on the higher side. An additional iteration was performed using foam for the front impact structure.

Front Impact

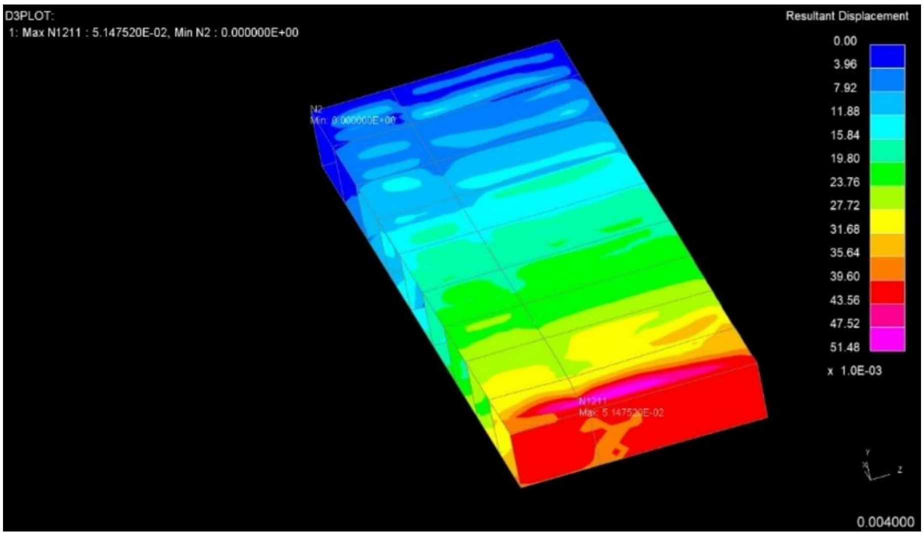

Figure 4 Plot for front impact without impact attenuator

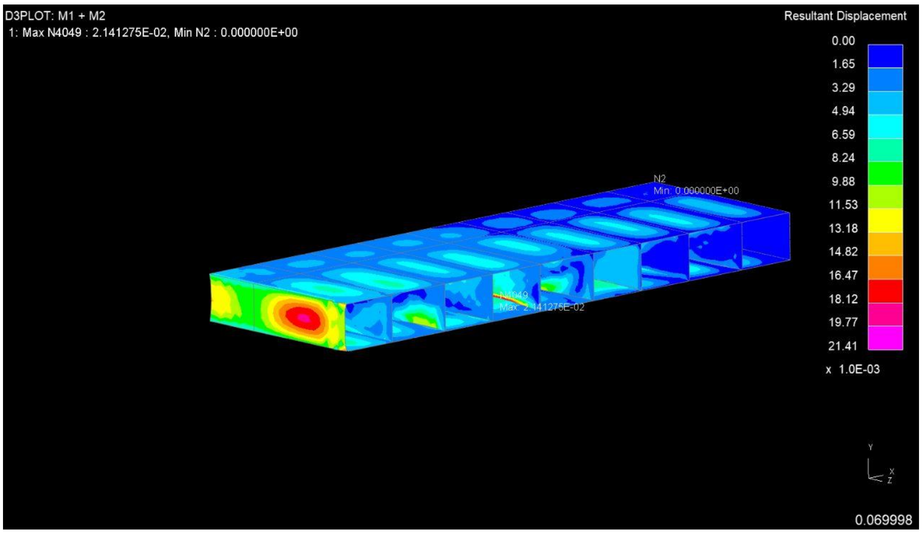

Figure 5 Plot for Font impact with attenuator aluminium

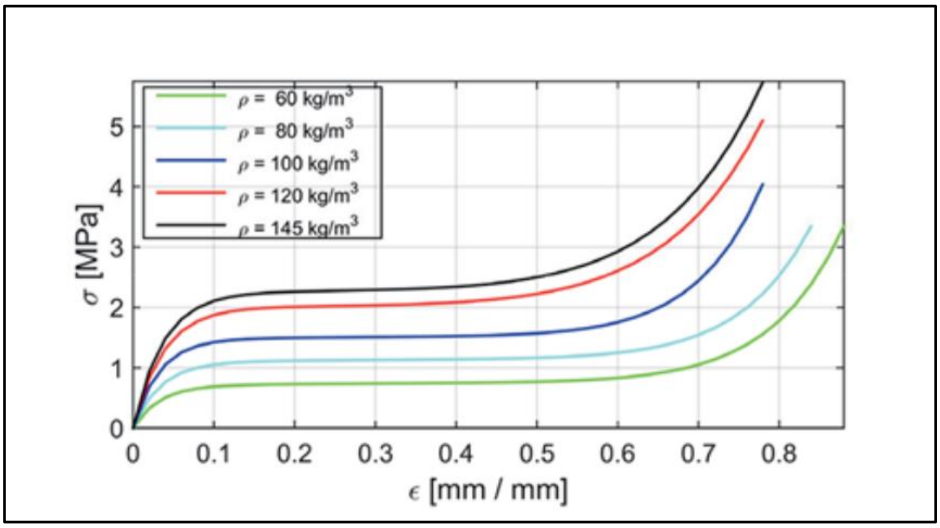

Table 6 Stress-strain curves obtained from analytical model for different PUR foam densities (Shaaban & Elsabbagh, 2021)

Side Impact

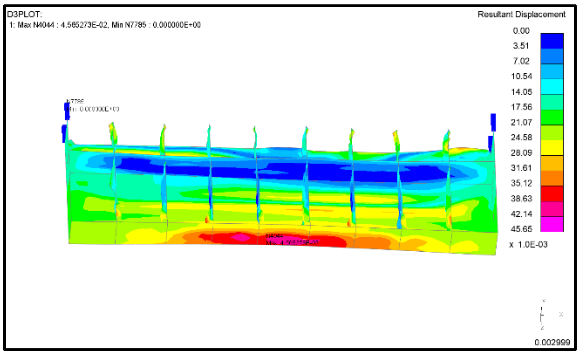

Figure 6 Side Impact Plot without attenuator

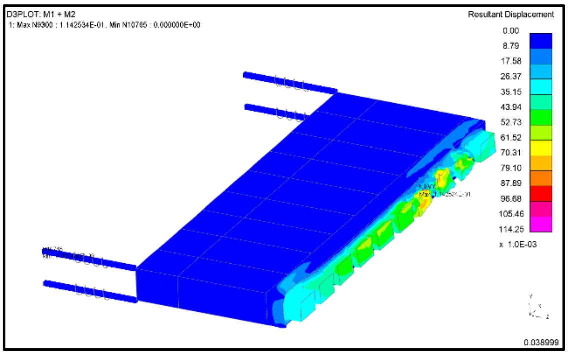

Figure 7 Side Impact Plot with attenuator

Figure 7 shows that the max energy has been absorbed by the attenuator reducing the damage on the main battery pack caused by external load.

Discussion

As per the received feedback for coursework-1, the initial test for the designed model resulted in significant damage to the battery enclosure indicating faults in the analytical calculation due to consideration of low loadings. The use of an impact attenuator was therefore more of a mandatory requirement in order to minimize the deflection and impact force acting on the battery enclosure. For modelling of the impact attenuator, the material selection and the design of the structure was a critical component. An iteration of modelling impact attenuator with different material was carried out, from this it was observed that using a material which had higher stiffness in comparison to the main material resulted in exceeding damage of the enclosure from rear side as well due to the fixed boundary condition. Among the considered option use of foam was the most ideal choice in order to minimise the forces acting on the main body for front collision, despite this due to the restricted available area for impact attenuator the minimum deflection criteria could not be matched.

The use of aluminium sheets for side impact attenuator demonstrated to be good choice as it was able to absorb maximum impact energy and protect the battery enclosure from severe damage due to external load and could meet the design requirement.

Limitations

- The results obtained from the FE analysis were different in comparison with analytical calculations due to consideration of lower loading.
- The boundary conditions specified in the FE tool is one of the factors for variations in result obtained from the analytical approach.
- Due to increased computational time associated for the simulation, a higher meshing size was used.

Improvements

- The thickness of the material laminates can be increased to increase the stiffness of the enclosure.
- The use of composite material can be used to for impact attenuators
- The deflection observed can be further minimised by using a better designed impact attenuators.

- Use of more precise values for nominal stress vs strain curve for defining material property of the foam could depict more realistic behaviour of the system.

Conclusion

In the following analysis we have validated the durability and performance of the designed battery enclosure using the FE element tool. This approach can be used to support and validate the analytical calculation of the design. The designed battery enclosure couldn't withstand the subjected forces which mimicked the frontal and side collision test, an external impact attenuator had be to be used in order to absorb the impact forces and minimise the deflection of the battery enclosure to protect the batteries and meet the intended design requirements.

References

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Chang, J. M. et al., 2007. Implicit and Explicit Finite Element Methods for Crash Safety Analysis. *Modeling, Testing and Design of Materials for Dummies and Structures for Crash Safety Applications.*

Gurumurthy, C. & Fang, J., 2020. *Modelling of glass fibre reinforced plastic for crash applications,* s.l.: s.n.

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Shi, D. & Xiao, X., 2018. An enhanced continuum damage mechanics model for crash simulation of composites. *Composite Structures.*